Internet of Water

INTERNET OF WATER REVISITED –
Building an Internet of Water

A REPORT FROM THE 2017 to 2019
INTERNET OF WATER ROUNDTABLES

THE ASPEN INSTITUTE

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The Aspen Institute is an educational and policy studies organization based in Washington, D.C. Its mission is to foster leadership based on enduring values and to provide a nonpartisan venue for dealing with critical issues. The Institute has campuses in Aspen, Colorado, and on the Wye River on Maryland's Eastern Shore. It also maintains offices in New York City and has an international network of partners.

The Aspen Institute **Energy and Environment Program** addresses critical energy, environmental, and climate change issues through non-partisan, non-ideological convening, with the specific intent of bringing together diverse stakeholders to improve the process and progress of policy-level dialogue. This enables EEP to sit at a critical intersection in the conversation and bring together diverse groups of expert stakeholders. In addition to energy and environmental policy, which the program has been addressing for several decades, EEP is now actively and purposefully engaging in climate change policy – mitigating the effects of climate change, adapting to the inevitable impacts of climate change, and facilitating the international cooperation needed to achieve these goals. https://aspeninstitute.org/ee

The Nicholas Institute for Environmental Policy Solutions at Duke University improves environmental policymaking worldwide through objective, fact-based research to confront the climate crisis, clarify the economics of limiting carbon pollution, harness emerging environmental markets, put the value of nature's benefits on the balance sheet, develop adaptive water management approaches, and identify other strategies to attain community resilience. The Nicholas Institute is part of Duke University and its wider community of world-class scholars. This unique resource allows the Nicholas Institute's team of economists, scientists, lawyers, and policy experts not only to deliver timely, credible analyses to a wide variety of decision makers, but also to convene these decision makers to reach a shared understanding regarding this century's most pressing environmental problems.
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The 2017 to 2019 Internet of Water Roundtables consisted of five moderated discussions held in different regions of the United States to discuss the findings and recommendations from the Internet of Water report released in May 2017. The Internet of Water Report was born out of a dialogue series hosted by the Aspen Institute, the Nicholas Institute, and Redstone Strategy Group in 2016 and 2017 to discuss how to improve our water data-sharing infrastructure. The impetus for the dialogue series came from the 2015 Aspen-Nicholas Water Forum on Data Intelligence for 21st Century Water Management. The annual Aspen-Nicholas Water Forum convenes a diverse group of experts to hold a moderated conversation around domestic water challenges in the 21st century.

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PREFACE

The Internet of Water report published in 2017 provided a series of findings and recommendations from the Aspen Institute Dialogue Series on Sharing and Integrating Water Data for Sustainability to address how to improve our nation's water data infrastructure to better equip and enable sustainable water resource management. Since this report, the Nicholas Institute was tasked with beginning to implement an Internet of Water (IoW). As an initial step, the Aspen Institute convened a series of conversations across the United States to learn about current water data activities, discuss needs and expectations of different communities, identify and strengthen collaborations, and imagine how the Internet of Water could be best implemented for their region or sector.

The Aspen Institute Energy and Environment Program in partnership with the Nicholas Institute for Environmental Policy Solutions convened five roundtable events (California, Great Lakes Region, the Midwest, Texas, and the Colorado River Basin) to have a moderated conversation with a diverse set of stakeholders in each region. Participants included experts and representatives from federal, state, and local government agencies, the private sector, academia and non-governmental organizations. The last two roundtable events expanded the scope of the Internet of Water conversation to include ongoing water data initiatives within the region (Texas and the Colorado River Basin).

This addendum synthesizes the perspectives from each roundtable – notably the similarities and differences – starting with the context for each roundtable and ending with an overall vision for building the Internet of Water. The governance models for hubs were explored, specific use cases developed, and policy and legislative opportunities and challenges identified. It was clear that sectors and regions are deeply interested in realizing the potential of their water data. Many were interested in the IoW providing a neutral convening and coordinating role to leverage ongoing activities and ensure the data infrastructure built will allow water data to flow seamlessly between sectors and regions.

This report is issued under the auspices of the Aspen Institute. Not all views expressed in the report are unanimous and not all comments reflect individual expectations or understanding of the roundtable events. We will continue to support these important discussions regarding the sharing and integration of open water data across the U.S. and its broader institutional implications. We hope that this report proves useful to the water data community in strengthening efforts to collaborate on shared standards and expectations that guide data sharing and overcome institutional norms and barriers.

We thank the following sponsors for their generous support of the Water Data Dialogue Series and Regional Roundtables: S.D. Bechtel Jr. Foundation; Kingfisher Foundation; Walton Family Foundation; Pisces Foundation; Wege Foundation (Great Lakes Roundtable); Monsanto (Midwest Agricultural Communities Roundtable); and the Water Foundation (Colorado River Basin Roundtable).

EXECUTIVE SUMMARY

The Internet of Water (IoW) envisions a world engaged in sustainable water resource management enabled through increasingly discoverable, accessible, and usable water data that inform real-time decision-making. The IoW report describes a federated network of data producers, hubs, and users. The original findings and recommendations from the report are located in **Appendix I, and are referenced throughout this addendum**. While the constituents of the IoW already exist; the connections between them are weak or non-existent. The mission for the IoW is to build, strengthen, and standardize a dynamic and voluntary network of communities and institutions to facilitate the opening, sharing, and integration of water data and information (Figure 1).

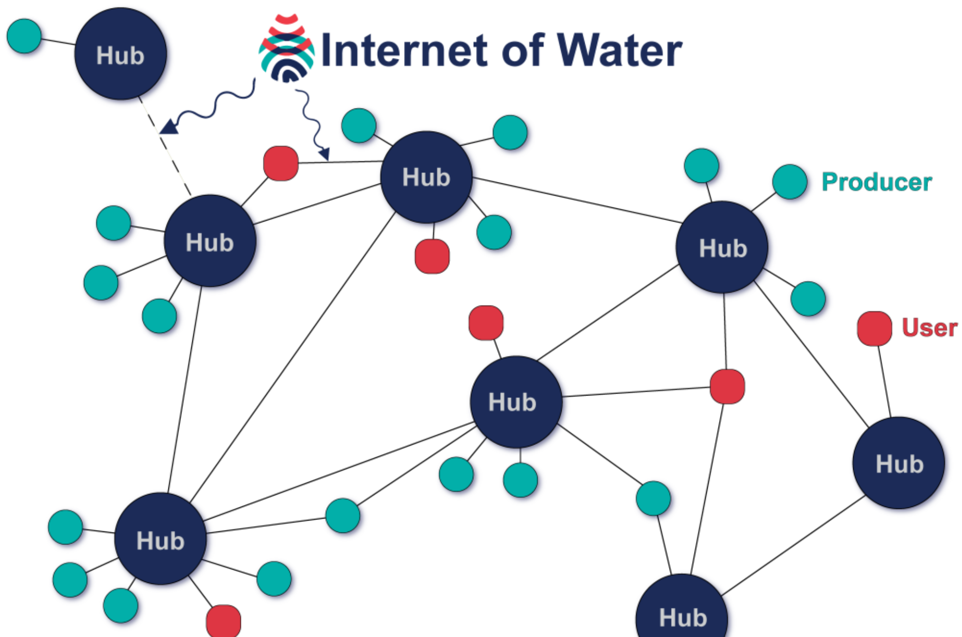

Figure 1: The Internet of Water connects producers, hubs, and users.

The Aspen Institute convened five roundtables from October 2017 to January 2019 in different regions of the United States (Figure 2) to draw perspectives for how the IoW could be integrated with current water data activities, meet the needs and expectations of communities, and strengthen collaborations. The roundtables included:

California (October 12, 2017) focused on the new legislative requirements of California's Open and Transparent Water Data Act (AB 1755) for state agencies to create and maintain a statewide platform integrating water and ecological databases.

Great Lakes Region (November 16, 2017) focused on how to better share and integrate a plethora of pre-existing data systems to address complex questions, particularly around water quality challenges in the Great Lakes and the rising costs to downstream, industrial communities.

Midwest Agricultural Communities (February 23, 2018) focused on the potential motivations and opportunities to share privately collected agricultural data while addressing data privacy and regulatory concerns.

Texas (April 16, 2018) focused on the rise of current water data initiatives in Texas, with an emphasis on ensuring the State's water security and capacity to respond to extreme events. There was strong interest in identifying the ideal process to prioritize which data to open to maximize the value for both public agencies and user communities.

Colorado River Basin (January 28-29, 2019) expanded the conversation beyond the Internet of Water to include additional national, regional, and state water data efforts in the Colorado River Basin. The conversation focused on how to coordinate, communicate, and leverage these initiatives to create a viable water data community that could move towards creating widely accepted standards for water budgets.

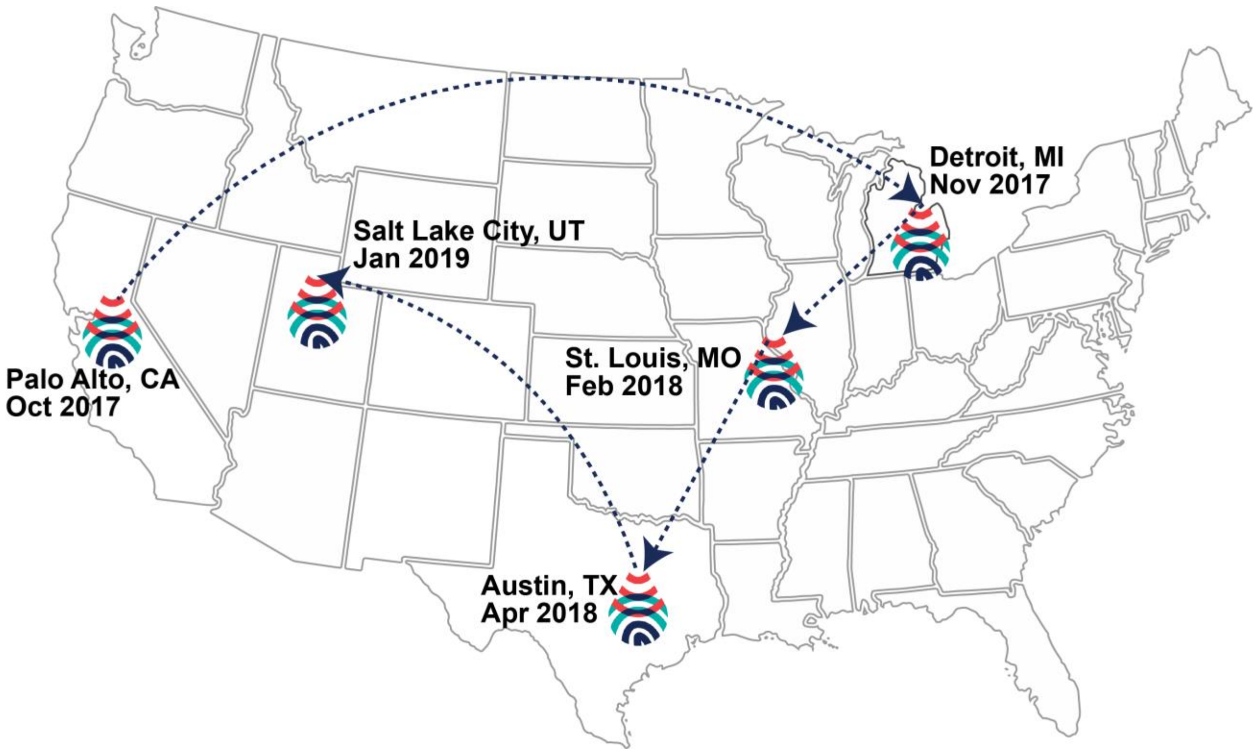

Figure 2. Timeline and locations of Internet of water roundtable events.

This report synthesizes these conversations and adds further texture to how the IoW could meet the water data needs of different sectors and regions in the United States. The roundtables highlighted the formation of new water data initiatives seeking to address complex water challenges across the nation. These initiatives are meeting the needs of their communities, yet there is little collaboration across communities to learn, share resources, and ensure water data are moving towards standardization. Thus, each initiative must reinvent the wheel. An IoW would provide tremendous value by connecting these efforts and collectively building financially sustainable, integrated water data infrastructure for the nation. To learn more about the Internet of Water visit https://internetofwater.org/.

INDIVIDUAL ROUNDTABLE SUMMARY

California

October 2017 in Palo Alto, CA

Water data became a cornerstone of new policies in California during the five-year drought (2012-2017). The drought revealed challenges to obtain the groundwater and utility data needed to manage water resources during this crisis. In response, the 2014 Sustainable Groundwater Management Act (SGMA) required local groundwater management agencies demonstrate the impact of their policies with data. In 2016, the Open and Transparent Water Data Act (Assembly Bill (AB) 1755) required the Department of Water Resources, Water Quality Monitoring Council, State Water Resources Control Board, and the Department of Fish and Wildlife to create and maintain a statewide, integrated water data platform by August 1, 2020. AB 1755 is the first legislative document to require a state to make water data open and discoverable.

AB 1755 came from the growing recognition that California needs an integrative approach to water management to mitigate extreme events arising from climate change and competing water uses. Currently, there are more than 30 state agencies overseeing more than 2,300 entities that manage some aspect of flood, water supply, or water treatment. Integrated data is a foundational step towards integrative water management. Agencies must develop protocols for data sharing, documentation, quality control, public access, and the promotion of open-source platforms and tools.

State agencies are collaborating with outside entities to expand beyond the minimum requirements of AB 1755 to ensure the long-term success of integrative water management. These efforts focus on the:

Development of governance and funding options. The State is working with Redstone Strategy Group to develop long-term governance and funding for the open water data platform.

Identification of use cases. The State is working with the University of California to identify more than two dozen use cases that lie along a spectrum of *existing use cases* where the data already exist to address current needs and *aspirational use cases* that require new data to address emerging issues (Principle 1.1, Appendix I).

Adoption of the Open Water Information Architecture standards. The State is working with the San Diego Super Computer Center to develop standards.

Creation of data challenges. The State hosts water data challenges to test and gain insights on the platform, protocols, and standards being developed.

AB 1755 put California into a leading role for advancing the sharing and integration of water data within a state. In March 2019, New Mexico became the second state to pass a water data act (HB 651). The legislature in these states may provide starting points for other states to develop policies to address their water data needs. An important question that emerges is whether there are common processes and principles to improve water data infrastructure that can translate between states with or without legislative mandates.

Great Lakes Region

November 2017 in Detroit, MI

The Great Lakes are international water bodies that hold 20 percent of the world's freshwater. They are governed by eight states and two provinces that compose less than 1 percent of the world's population. Water quality is a continual challenge for the Great Lakes with impairments originating from pipeline spills, sinking ships, invasive species, and the accumulation of nutrients and pollutants from upstream sources. The Great Lakes region is committed to stewarding this resource well and have put in place policies and compacts formalizing governance structures, roles, and responsibilities to facilitate cooperative decision-making. While these formalized structures exist, much of the activities and decision-making remains decentralized and surprisingly isolated. For instance, the region collectively spends around $3 million annually on restoration projects, but the individual and cumulative social, cultural, economic or ecological impacts are not known because data are either not collected or not shared.

In some respects, the Great Lakes region is awash in data but poor in information. There are several groups collecting data to meet specific needs. The Great Lakes Environmental Research Laboratory (GLERL) focuses on providing information to guide decisions that lead to safe and sustainable ecosystems. The Great Lakes Observing System (GLOS) partners with 17 federal agencies to coordinate monitoring and restoration efforts by the federal government. The Great Lakes Commission hosts Blue Accounting to use data to assess the efficacy of ecosystem investments and manages the Great Lakes Regional Water Use Database to provide information on withdrawals, diversions, and consumptive use. Each of these efforts collect data, but these data are rarely connected and shared between groups. For instance, while NOAA funds both GLOS and GLERL, the data are often not discoverable or shared between them. Many of these efforts consider themselves to be hubs; however, there is not a platform integrating and providing standardized data across these efforts to address holistically the water challenges throughout the region.

The Great Lakes region was unique in that there are already many organizations collecting data and formalized relationships have already been developed over decades between international, federal, state, and local stakeholders. Despite formalized relationships, the institutional, not technical, barriers continue to hinder data sharing. The presence of strong institutional relationships may allow this region to accelerate addressing institutional barriers to data sharing. The group raised questions around who would take responsibility for building data sharing capacity and for providing technical assistance as these tasks fall outside the boundary of their current mission and require funding resources. Some felt a neutral third party would need to take on this responsibility and/or provide a coordinating and convening role in the Great Lakes (Recommendation 3.1. and Principle 3.3, Appendix I).

Agricultural Communities

February 2018 in St. Louis, MO

This roundtable was distinct in two respects. First, it focused on a specific sector, agriculture, rather than a region. Second, it focused on local government and private data rather than data collected by state or federal agencies. The agricultural community, as the largest consumptive water user in the United States, is a key partner in the sustainable management of water resources. The regulated agricultural community provides some data to public agencies, but many agricultural communities are exempt from reporting. In some states, farms that use less than 10,000 gallons per day do not have to report water use or acquire National Pollution Discharge Elimination System permits. The cumulative impact of these farms could represent significant gaps in a water budget (quantity, quality, use). Additionally, many farms rely on groundwater, and their well data could drastically improve the spatial and temporal resolution of groundwater levels in aquifers across the nation. However, these data are private and rarely shared. Similarly, significant gaps in water data occur on private lands, which represents the majority of land in the United States. Land use affects water quality and data may need to be collected and shared from private lands to improve water quality at scale. This raised two key questions: (1) what data are needed to manage water resources sustainably and (2) are publicly collected data sufficient to manage our water resources?

The answers to these questions must start with identifying what public data already exist through legislative reporting requirements. Second, what data are open and what data remain in non-machine-readable formats and/or are located within irrigation district, conservation district, or state agency filing cabinets? Third, what publicly funded data collected by universities, citizen scientists, and NGO's exist but are not discoverable or accessible? The group generally believed that private data should not be sought until these public sources of data were made discoverable, accessible, and usable (aligns with Finding 2, Appendix I). Private entities, such as the agricultural community, may care deeply about the environment and desire to share data; however, too often the voluntary sharing of data resulted in reputational harm and/or additional regulations. As such, it is important to ensure public data are discoverable and open prior to making overtures to private industry for their data. It will also be necessary to establish trust, address data privacy concerns, and mitigate the risk of misinformation.

While participants from the agricultural community encouraged the IoW to focus on public data initially, they also noted two important trends. First, there may be no such thing as privacy in the future as new technology (such as sensors and satellites) improves in estimating water quantity, quality, and use across the landscape. It is important for the legal structure around data privacy to keep pace with technological innovations. Second, more regulations are coming (SGMA in California, Mississippi groundwater law changes, Des Moines lawsuit in Iowa, etc.). Agricultural communities have an opportunity now to set terms around data sharing to ensure that appropriate safeguards are in place before regulations come. This discussion added new and important insights, particularly regarding Recommendation 2.3 (Appendix I).

Texas

April 2018 in Austin, TX

Texas has a long history of relying on data to manage their water resources across diverse climates and geographies. Prior to the internet, the Texas Water Monitoring Council coordinated federal, state, and local data and efforts. The Council disbanded in the mid-1990s because it believed the internet would provide the mechanisms needed to share water data. Unfortunately, without this coordinating effort, state agencies began collecting different data with different standards and with different levels of sharing. The Texas Natural Resources Information System provides all types of spatial data, including water resources. The Texas Water Development Board (TWDB) collects water quantity and planning data used to support the development of a state water plan every five years. The Texas Railroad Commission collects water data relevant to oil and gas. The Texas Commission on Environmental Quality collects water quality, water rights, and service provider data. Much of the historic data remain in non-machine-readable formats, and the discoverability and accessibility of machine-readable data are not standardized. Many data users have expressed frustration with the amount of effort it takes to discover and access water-related data.

The TWDB, perhaps more so than other state agencies, has worked towards making data more interoperable because of its involvement in developing the State Water plan. The State Water plan legislatively requires the TWDB to integrate 16 regional water plans to create one overall State plan. The standardization of data across regions would tremendously facilitate the creation of the State plan. The TWDB is also responsible to assist in emergency management situations. Hurricane Harvey in 2017 highlighted the need to improve the state's data infrastructure as emergency managers had to access more than 14 websites to get the data needed to make decisions in the midst of a crisis. The TWDB has a proposal in the state legislature for funding to create an integrated data and information platform to assist in real-time decision-making.

Private companies within Texas, such as the oil and gas industry, collect tremendous amounts of water data for their operations. Several companies recognize the importance of sharing their data to avoid tragedy of the common events with water resources, particularly with wastewater disposal. The volume of produced wastewater currently exceeds the disposal capacity of injection wells, requiring the oil and gas industry to innovate around recycling and reusing produced water both within and across individual companies. The oil and gas industry is not clear on how they would make their data available without compromising important privacy concerns, but they recognize the important information that their data provide to the broader public and water resources management. Many would request anonymity and aggregation of their data by a neutral third party, as well as robust data privacy policies (Principle 2.4, Appendix I).

Upper Colorado River Basin

January 2019 in Salt Lake City, UT

The Colorado River Basin sits within multiple legal frameworks from state water rights to interstate and international compacts. The successful management and administration of these legal frameworks is becoming increasingly challenging with growing water demand and climate change. Improvements to water data infrastructure are essential to better manage and address these challenges. In addition to the IoW, this roundtable highlighted the Western States Water Council's Water Data Exchange (WaDE) Program and the NASA-Desert Research Institute's OpenET project.

WaDE was launched in 2012 following a report by Sandia National Laboratory that highlighted the difficulty in finding, accessing, and comparing state administrative water data (planning, rights, use estimates, etc.). WaDE works with the 18 western state governors to provide a single platform to discover administrative water data, with future goals of improving accessibility and interoperability. WaDE is successful because of its long-term relationships with states and its ability to raise funding for states to participate in the program.

OpenET will fill one of the largest gaps in water use data by providing open, easily accessible, and spatially explicit evapotranspiration (ET) data. OpenET models the consumptive use of plant evapotranspiration based on satellite and other readily available data. OpenET is iteratively designing their platform to meet the technical and communication requirements of their user communities in terms of spatial resolution, timeliness, accuracy, and accessibility of ET data. The OpenET community desires for this platform to build consensus and trust around how to measure consumptive water use, as well as develop best practices and tools for quality assurance with satellite imagery, model assumptions, and metadata provision.

There are several collaborative water data initiatives in the Colorado River Basin; however, there is limited collaboration across initiatives. In order to leverage water data initiatives, there needs to be a "head librarian" that facilitates and coordinates ongoing conversations across the water data community and provides a clearinghouse for initiatives, catalogs, definitions, standards, etc. (Principle 3.3, Appendix I). The head librarian can provide guidance on agreed-upon minimum standards to ensure data are correctly placed on the shelf (cataloged) to be discoverable by end users. The head librarian would be the go-to resource for new data producers and hubs, and provide a place for groups to convene and communicate. This is a primary role for the IoW (Action 3, Appendix I). The IoW would catalog existing efforts and build awareness, so each state, hub, and initiative are learning from each other's novel solutions and experiences. The IoW could provide resources for OpenET and WaDE (and others) to serve as library branches that convene meetings and working groups for their particular communities (Action 2, Appendix I). The regular convening of the same set of stakeholders could build relationships that move from identifying terms and standards to actually reconciling and advocating for standardized definitions to their respective communities. The IoW can provide the space for OpenET, WaDE, states, and other efforts to share their use cases that demonstrate the value of water data for different communities, potentially enabling new actors to invest in water data (Action 1, Appendix I).

HOW TO MAKE EXISTING PUBLIC WATER DATA OPEN?

"*Data should not be in search of a problem, but a problem should be in search of data.*" Indeed, public agencies collect data for a specific purpose. Sharing enables the data to be put to new uses outside of the original data-collecting agency, but how do public agencies prioritize which data to make open? All roundtables focused on this question and how to make the trade-offs between making all public data open (Finding 2, Appendix I) and not limiting the potential value that could be created versus focusing on making only those public data with clear benefits and end uses open to ensure value is created (Finding 1, Appendix I).

The potential consequences of these trade-offs were highlighted in the Great Lakes roundtable where participants noted that most data hubs are transient and disappear within a few years because the hubs (1) lacked the focus and specificity needed to be relevant to a community and/or (2) lacked sustainable financing mechanisms. The high rate of hub failure has eroded trust in data producers and users to rely on hubs.

The primary causes of hub failures seem to support Principle 1.1 (Appendix I) in the IoW report, which says that economically viable hubs need to develop a community of users. However, creating hubs around specific use cases raised concerns that "hub graveyards" may grow and water data become increasingly fragmented. What is the balance between creating a few large data only hubs versus a multitude of hubs organized around providing both data and information for specific topics? This line of questioning led regional roundtables (Great Lakes and Colorado River Basin) to explore the use of catalogs to make data discoverable and create an ecosystem that could move towards increased interoperability of data between hubs.

All Data: If You Build It They Will Come

Private companies (data users) and the federal government (since all public data are meant to be open) primarily advocated for sharing all public water data. This approach was deemed "if you build it, they will come", because the data are simply made open through a catalog. Proponents of this approach highlighted that all data should be shared because you cannot foresee the potential uses and users for the data. For instance, California's Irrigation Management Information System was designed for agricultural end users to inform irrigation decisions, but has been used for a diverse array of activities from pest management to lawsuits involving automobile accidents. Providing only those data that have a specific end use in mind could potentially eliminate future stakeholders and end uses. Even if data are not open, many private entities simply want to know if the data exists and who to contact (Recommendation 2.1, Appendix I).

The primary criticism of this approach was that significant resources may be spent to share data that are never put to use. Hubs that open data without any community engagement will struggle with attracting end users to create value from the data. Indeed, public agencies that have tried this approach found that the "if you build it, they will come" mentality does not work for water data. These agencies have found that they must develop analytics and information services with the data to create value to their citizens. Hubs located outside of public agencies that take this approach will likely join the hub graveyard.

Use Cases: Who Needs What Data for Which Decisions

State agencies frequently noted the lack of human and financial resources to invest in data unless there are clear value propositions that highlight how improved data infrastructure (1) help organizations more efficiently meet their missions, (2) have a positive return on investment, and/or (3) address a specific need. These value propositions, often referred to as use cases, are needed for there to be substantial, long-term investments in data infrastructure. Data producers and hubs championed the approach of building data and information services around use cases that clearly identify "*who* needs *what* data for *which* decisions." Such an approach will help prioritize which data to share and increase the likelihood of creating value. It is not surprising that the data producers and hubs (those that bear the cost of data infrastructure) would be proponents of prioritizing efforts that ensure value creation. California and the Great Lakes region were strong advocates for a use case approach. However, these hubs may jeopardize their neutrality and trust with the broader community. Additionally, important data and insights could remain undiscovered if hubs focus only on providing certain types of data for use cases.

This approach requires greater up-front investment as hubs work with users to identify use cases and develop usable interfaces between the data and end users. For instance, operators may need real-time data, the public is interested in seeing data converted into information in the context to a specific question, and a commissioner needs a sentence with a number. Data are most usable when delivered in a context that is meaningful to the end-user. This iterative approach is expensive and the initial use cases should have a concrete financial impact, as well as measuring hydrological, societal, or economic outcomes to get further investment. Hubs outside of state and federal agencies that attempt to form without building a community of users are at high risk for joining the hub graveyard.

A Combined Approach

Several roundtables ended this conversation by admitting both approaches might be viable and necessary. The use case approach will help to prioritize data efforts, demonstrate value, and create the public demand needed for local and state governments to invest in their data. This approach can also help build engaged communities that champion water data and develop relationships that help move more contentious data towards agreed upon definitions and standards (Recommendation 1.2, Appendix I). As these data become more standardized, new uses and users may emerge and create demand for additional data to be open. Those users will need to know what data exist in order to know what is possible to build. At the very minimum, all public data should be discoverable even if they are not currently accessible or interoperable (Recommendation 2.1, Appendix I).

THE VALUE OF WATER DATA

The first action in the IoW report was to articulate the value of water data to different communities and sectors through use cases. Use cases provide opportunities to create trust because they require collaborative efforts to build agreement around data, standards, and methods. Community engagement and trust are crucial for data to be put to use and create real, sustained value. Hubs could provide the governance structure to build communities that include data producers, data users, technical staff, and policy-makers to ensure the viability of the use case in meeting the needs of end users. Ideally, these communities will then become the voice and champions of water data. There were some general value propositions for data across use cases. A few specific uses to each roundtable are briefly described.

General Value Propositions

Communication. Data can be a powerful tool to inform and educate the public through avenues such as individual benchmarking, performance metrics, and explaining decision-making (such as curtailment in drought). Data are increasingly synonymous with story-telling. Telling stories with data requires improved data literacy in the public sector. There also needs to be a culture of learning and recognizing that new data may change our understanding of other data, creating a shared and adaptive learning environment.

Improved Decision-Making. *You can't manage what you don't measure* (or can't find/access). Data can help improve the efficiency and effectiveness of water resources management from the coordination of real-time operational decisions to long-term water and infrastructure planning. Policies can be made, and effectiveness measured, with data.

Improved Efficiencies. Public agencies often have different departments collecting their own data with little sharing between departments. Improving data sharing mechanisms within and across agencies can remove unnecessary redundancies and create improved efficiencies. Staff spend less time collecting duplicative data, searching for data, and responding to external Freedom of Information Act requests. Entities external to the public agency will spend less time searching for and cleaning data, and more time innovating.

Risk Management. Water is an interconnected resource and efforts made by one entity are unlikely to have a significant effect on the overall quantity or quality of water in a watershed or aquifer. Many entities increasingly recognize the need to manage water risks holistically across river basins and aquifers. Shared data are needed to understand the quantity, quality, legislation, and upstream contexts affecting water resources. These data enable a collective understanding of the risk to water resources.

Transparency. A suite of common, standardized data available to all parties could provide a common platform for understanding water challenges (an agreed upon "water truth"), build trust across constituencies sharing water resources, and reduce liabilities and costly litigation. Data transparency also helps agencies to provide validity to their narratives and create trust with the public.

Roundtable Specific Use Cases

California

University of California **use cases.** These use cases include planning and financing groundwater recharge projects, managing environmental flows for salmon protection, creating groundwater budgets, developing delta water quality standards, managing water transfers for environmental purposes, and reducing uncertainty to obtain capital investment in headwater restoration projects.

Aquifer Recharge. The drought crisis led to renewed interest in groundwater management and the use of floodwater for aquifer recovery. Pre-existing groundwater and recharge data (often not collected) are needed to optimize groundwater recharge during flood events and have the potential to create huge financial value in reduced pumping costs.

Regulated Community. Agricultural communities, industry, and utilities often expend substantial resources to comply with reporting requirements. A value proposition for the regulated community would be the development of automatically transmitted, standardized data to regulatory agencies. This would reduce the cost burdens on these communities, create transparency, and produce trust.

Utilities. The drought crisis revealed that most water utilities could not answer basic questions, such as whether they could meet demand during the drought. Utilities presumed adequate water supply and had either not collected or not analyzed water supply and demand data. The legislature has put pressure on water utilities to collect and make those data available to ensure water security and resiliency in future drought events.

Great Lakes

Impact Assessment. There is interest in sharing data to understand the impact of current investments in restoring and maintaining the Great Lakes ecosystem in order to inform whether to invest in similar initiatives.

Infrastructure. Sharing data across utilities could create opportunities that lead to tremendous savings and improved water resources by answering questions such as: can a deployed sensor network be applied to pre-existing infrastructure to understand latency in the distribution system? Can energy usage be decreased by 10-20% in the distribution systems to create financial savings of $70-90 million? Where is the most cost effective location to invest in green infrastructure and increased storage capacity in the watershed?

True Cost of Water. Businesses are interested in understanding the true cost of water as part of their operations (buy, treat, and dispose), as well as the social costs of water. Access to these types of data, primarily from utilities, would help water intensive businesses make decisions on where to site new plants or invest in a water intensive product at pre-existing plants.

Water Technology Innovation. Currently, water technology companies often cannot find the necessary data or metadata from local governments, utilities, or agricultural communities to develop technologies with a large enough market to create a positive return on investment. Shared data could enable water technology companies to create relevant products and applications that can be brought to market.

Agricultural Communities

The agricultural communities framed use cases for sharing private data in terms of opportunity costs.

The cost of debate. The lack of standards creates debate about which data to trust, how those data can be used, and what is the "water truth." This is particularly true for consumptive water use and estimating the amount of water needed for irrigation (also noted in the Colorado River Basin roundtable). Having access to all the data and methods will allow the public and private sector to avoid the cost of debating the baseline data and litigation that arises from poor data and/or low transparency.

The cost of inefficiency. Too much time is spent discovering and cleaning data, with little time for growers to develop innovative solutions. Growers are ready to adopt new technologies and data sharing initiatives if it will improve their operational efficiency and/or funding is provided. It is not clear that these data need to be made publicly available since private businesses have more resources to create actionable information.

The cost of misinformation. Shared data can enable growers to quickly identify and address emerging problems and avoid increased regulations. In the case where new regulations are implemented, having data readily available could enable precision management for, and precision regulation of, agricultural communities rather than placing extra burden on all growers. Growers can also share data to validate model estimates of water quantity, quality, and use in order to ensure these public estimates are accurate and avoid the potential for reputational harm.

Texas

Extreme Events. Drought, rapidly growing cities, and a booming oil and gas industry are creating water security concerns that are difficult to address because different sectors hold different pieces of data. Similarly, flood events and hurricanes are showing the limitations of current data infrastructure systems as emergency responders visit multiple websites to find the information they need to make real-time decisions. Texas is interested in creating integrated platforms to better respond to extreme events and plan for future water security.

Groundwater. There are 98 Groundwater Conservation Districts (GCDs) managing groundwater use in Texas. There are large discrepancies between the human, financial, and technical capacity of GCDs, as well as the types of data and the standards used. The Texas Alliance for Groundwater Districts assessed the interest of GCD's in improving their data infrastructure and developing decision support tools. Some GCD's are interested in improving their data to increase operational efficiencies and water availability (see box Clearwater Underground Water Conservation District); however, others were concerned that sharing data would result in loss of autonomy and raise the potential for increased regulations.

Clearwater Underground Water Conservation District

The Clearwater Underground Conservation District initially relied on individual licenses for a desktop GIS. The district transitioned to contracting with a company that could build a geospatial platform that held all their data for $250,000 in upfront costs and $4,000 per year to maintain. The District began digitizing paper files in cabinets showing well locations, correcting some locations while in the field. Now, properties could easily be searched and combined with other data. For instance, the agricultural community loved the addition of NOAA data to inform drought insurance decisions. Realtors used their website to assess the status of septic tanks prior to selling or buying a property. The platform adds tools and features to meet end user needs. The geospatial platform was affordable because of the influx of capital from new tax revenue generated by rapid population growth. The District also could avoid internally hiring someone who cost more than the director of the District.

Utilities. One location may have three different water utilities managing drinking water, wastewater, and stormwater separately. Even within a single utility, data systems are often divided between departments (financial, customers, consumption, etc.). Utilities that have internally combined data systems report large increases in efficiency and greater capacity to understand and address issues (such as nonrevenue water). Some utilities are interested in sharing data externally to understand how they are performing relative to other utilities in terms of maximum daily flow, peak hourly flow, per-capita water use, non-revenue water loss, and so on. This provides opportunities to seek advice from better performing utilities in those categories and improve performance and efficiencies that lowers cost and enhances customer relations. Similar to the GCDs, some utilities are reticent to share data externally because exposing themselves to additional reputational and regulatory risks.

Water markets. Currently, some districts manually operate diversion gates and use different methods to estimate how much water flows through the diversion using paper records. The data infrastructure and implementation of standards are necessary for viable water markets to form in Texas. Upgrades to data infrastructure may be incentivized through regulatory requirements such as environmental flows.

Colorado River Basin

Water Budgets. The collective data challenge discussed was consumptive water use data. Accurate, high spatial and temporal resolution consumptive water use estimates could help create timely water budgets throughout the river basin and across state lines. There are immense legal and administrative challenges around moving towards a standardized set of data for consumptive water use (see Legal and Administrative Implications in the next chapter). The development of water budget pilots could provide a platform for constructive conversations at the intersection of technology, policy, and law.

CHALLENGES FACING AN INTERNET OF WATER

The roundtables highlighted four primary concerns that need to be addressed when implementing an IoW in a region or sector: (1) controlling the message and the risk of misinformation, (2) lack of technical capacity, (3) legal and administrative implications, and (4) data quality.

Controlling the Message and the Risk of Misinformation

Arguments against open data typically centered on security concerns and reputational risks. First, numerous security breaches and threats have required federal and state agencies to heighten IT security, which creates challenges to open data. Second, there is reputational risk that comes with open data because agencies lose control of the messaging and risk the data being misused (either accidentally or intentionally). The public often view data as correct and immutable, and most public agencies do not have the resources needed to address and overcome the reputational harm from misinformation. This concern was present across the board: water utilities, agricultural producers, and state agencies. There was also a sense that the data producers needed to be able to translate and interpret the data for the public and that opening the data would preclude this potential translation step.

Utilities and growers were particularly reticent to make their data available because historically it has led to increased regulation. They also shared deep concern for their data being used incorrectly for benchmarking purposes (e.g., utilities might have different definitions for peak demand) that results in reputational damage. Growers might be benchmarked for water use without taking into consideration climate, soil, etc. Additionally, providing data risks increased regulation, particularly when a utility or grower has never had the opportunity to analyze the data prior to making it open. The majority of local organizations articulated a need for some type of safe harbor from regulations or anonymization of data (e.g., aggregate water use at the watershed scale) (Principle 2.4, Appendix I).

Some agencies, such as DC Water, believe that radical transparency will create greater trust, along with better innovation and more cost effective solutions (see box Radical Transparency at DC Water). Open data could provide an opportunity for messaging and education, as well as improve access to data and information that might otherwise become privatized, creating inequalities and mistrust.

There is a tension between (1) keeping data private to avoid misinterpretation but perhaps reducing trust with (2) making data open and risk misinterpretation but perhaps gaining trust. One novel suggestion to mitigate this tension is to establish data stewards, individuals designated as points of contact, to provide messaging and context around datasets as they are released. Data users and journalists would go to the data steward to verify analyses, clarify potential uses, and ask questions. Data stewards would serve as trusted ambassadors for water data.

Radical Transparency at DC Water

There are over 150,000 public water systems in the U.S. with varying degrees of human, financial and technological resources to invest in their data infrastructure. Utilities have traditionally been "stealth agencies", believing consumers should not know a water utility exists because good quality water is always available at their tap. The times when utilities are in the spotlight have been when the system failed. Lead contamination provides a prime juxtaposition of responses. In 2015 Flint, Michigan had contaminated water quality from lead that began to be leached from water lines after the water supply sources changed. Similarly, D.C. Water faced a lead contamination crisis in 2001 due to pipe corrosion. Flint responded as a stealth agency and today the public buys bottled water because they do not trust the utility. D.C. water responded by publishing their lead lines data online and today have the trust and support of their residents. Public health crises, along with political and regulatory structures in some states, are helping to shift the culture for utilities to become more public facing and transparent with their data.

Lack of Technical Capacity

The capacity to hire and retain highly skilled technical staff is challenging for public agencies. Public salaries simply cannot compete with private industry, particularly in the sector of data science and IT. Two options were proposed as a means for public agencies to have access to highly skilled technical capacity. First, public agencies could cost share technical staff to provide a competitive salary. Second, the IoW or other organizations could provide technical resources or create a volunteer group of data scientists that public agencies can contract with on an as-needed basis. These options may provide access, albeit somewhat unreliably, to technical resources.

There are also mechanisms to build pre-existing technical capacity within organizations by creating tailored learning environments. Stack Exchange is a ground-up community clearinghouse of question and answers. A Stack Exchange for water data could be developed to answer public agency questions and provide how-to resources for centralizing, managing, and cleaning data. The volunteer network of data and information scientists could provide support to public agencies by providing answers and guidance. Similarly, developing peer learning networks provides an avenue for data producers, hubs, and users to share standards, definitions, processes, and so on for updating data infrastructure and creating value. Sharing successes and challenges can create an adaptive learning environment around best practices, processes, and technology. Technology is inherently scalable and may provide opportunities to develop more cost effective solutions. The open source community enables many hands to lead to innovations and streamlined processes.

Legal and Administrative Implications

Legislation provides stability and certainty, adapting thoughtfully over time. However, rapid changes in technology are producing disruptions that often exceed the capacity of the law and regulatory agencies to adapt in a timely fashion. This creates a tension between adopting new technologies to improve efficiencies and maintaining the regulatory status quo to reduce risk.

The Colorado River Basin roundtable highlighted legal and administrative challenges that arise when working towards standardizing consumptive water use. First, federal, state, and local agencies have different definitions for consumptive water use – a critically important aspect of the water budget. Second, measuring consumptive water use, particularly from ET is difficult, resulting in the development of multiple methods that produce different ET estimates. Third, any attempt to standardize a definition and method will have legal and administrative implications, requiring ongoing legal and administrative conversations to create trust and buy-in by states and communities. Participants at the roundtable suggested four approaches, similar to those proposed by the agricultural community to share private data, to begin moving towards developing consumptive water use standards.

Short-term, voluntary pilot studies can implement new standards for consumptive water use within a region without litigation or the threat of losing water rights.

Safe harbors can create smoother transitions when new data or methods are anticipated to be disruptive. Safe harbors that protect entities from the legal ramifications of adopting standardized consumptive water use estimates may improve acceptance.

Identify win-win situations where data build trust and create mutually beneficial solutions instead of winners and losers.

Convene regular meetings and working groups to build communities and relationships between the same set of stakeholders. Continued relationships are essential to move from identifying terms and standards to reconciling and advocating for standardized definitions.

Data Quality

"Just get the data out there" was a common mantra in the IoW report. Principle 2.2 (Appendix I) of the IoW report highlighted the tension between adopting water standards to improve data quality (and subsequent trust and value) while being careful to not exclude large amounts of data collected without standards. Many states recognize that there are problems with the data and they are reticent to share questionable data. There is an opportunity for data users to work with producers and hubs to identify and address systemic data quality challenges. For instance, California is working to identify minimum standards that will include as much data as possible into their integrated platform while ensuring a level of quality control and trust with the user community. They rely on users to identify errors and provide the State with opportunities to correct and improve the data. More established data protocols will be adopted iteratively over time through conversations with data producers and users.

Metadata are data about data. Standardized metadata are critical for hubs to increase data discoverability, accessibility, and usability. There was broad consensus across roundtables that data producers should maintain ownership of their data. Data producers are also responsible for providing adequate metadata for end users to make informed decisions about whether the data are fit-for-purpose (Principle 2.3, Appendix I). Maintaining the link between the original data producer and the data will become increasingly important to ensure data integrity as data are shared through a network of hubs.

BUILDING AN INTERNET OF WATER

The roundtable events revealed many ongoing, innovative water data efforts. Currently, there is no mechanism for transactional learning across efforts and collective movement towards interoperable water data. There was a repeated desire for the IoW to provide a strategic vision and coordinating role so these efforts may learn and build from one another. The IoW should provide the following functions: (1) community building, (2) technical capacity support, and (3) financing data infrastructure. Lastly, while the primary focus of the IoW will initially be public data, there is an awareness that privately collected data may be critical to successfully manage water resources in some regions of the United States.

Community Building

The IoW should become the head librarian for water data (Principle 3.3, Appendix I). The head librarian can provide agreed-upon minimum standards to ensure data are correctly placed on the shelf and discoverable by end users. It is whom new data producers and hubs visit to ensure their data can be put onto the same shelves as other comparable data. The head librarian provides a place for groups to convene and communicate with one another. The head library provides a clearinghouse for data efforts, standards, definitions, lessons learned, best practices, value propositions, and so on. In this manner, the IoW could serve as a matchmaker and convener, cross-pollinating innovation between regions and sectors, and building awareness so each state, hub, and project can learn from each other.

The IoW could also facilitate regular convenings and working groups to continue building communities, and/or provide resources for efforts. For instance, OpenET and WaDE can serve as library branches that convene meetings and working groups for their particular communities. Regular convening of the same set of stakeholders can build the relational capital needed to progress from identifying terms and standards to reconciling and advocating for standardized definitions to their respective communities. These smaller communities can (1) create trust around open data and mitigate against misuse, (2) share human resources and technical knowledge, and (3) participate in use cases that build agreement around data, standards, and methods to demonstrate the value.

Hubs such as WaDE, OpenET, and CUAHSI could provide standards, processes, and tools for water data collected from new technology to become discoverable, accessible, and usable. For example, WaDE and CUAHSI are developing protocols for sensor data. OpenET and the Bureau of Reclamation are working on protocols for ET and consumptive use estimates from satellites. NGO's are using EPA approved sensors to collect higher spatial and temporal frequencies of water quality data. IoW is looking at the possibilities and insights for incorporating water quantity, quality, and use data from utilities. The combination of these efforts requires ongoing coordination and communication to ensure common standards are recommended and/or adopted.

Technical Capacity Support

Technical capacity refers to the development of catalogs of data, definitions, standards, metadata, and exchange standards, as well as creating crosswalks between different types of data (Recommendation 2.1, Appendix I). The catalogs pull this information together and enables communities engaged in certain types of data (such as OpenET with consumptive water use and WaDE with administrative water data) to work towards standardization.

Data Dictionary

Public data are collected for a primary purpose. Embedded in the data are definitions. A data dictionary that shows the diversity of definitions, methods, and QA/QC for public water data is essential for data to become interoperable. There are ongoing efforts to create pieces of this data dictionary; however, there is not a single dictionary. The IoW would work with different water data initiatives to create the data dictionary, with an aspirational goal of facilitating conversations within these communities to come to agreement on preferred definitions and data collection protocols.

Metadata Catalog

Metadata (data about data) are essential for data to be (1) usable and (2) used correctly. Data producers are responsible for providing adequate information about the data for end users to decide if the data are fit-for-purpose. Data users are responsible for having good data literacy and domain expertise to use the data correctly. These roles mirror Principle 2.3 (Appendix I), with the addition that hubs bear the responsibility for ensuring the integrity of the original data provided by the producer. Misinterpretation and misuse will be more prevalent in the absence of good metadata. A metadata catalog would identify what metadata standards are available and which agencies have adopted those standards. The next, aspirational step would be for entities to agree upon, and adopt a suite of minimum metadata standards for different types of water data.

Metadata will become increasingly important for the inclusion of data in hubs. Federal and state agencies are becoming increasingly reluctant to accept data collected using non-standardized methods or non-standardized metadata from external entities because they cannot verify data accuracy. For example, irrigation districts are asking Utah's DWR to host their data online. However, Utah does not have a process for accepting and hosting local data of unknown quality. This raises a fundamental question of whether it is the role of state and federal agencies to host water data from other sources or if should there be dedicated hubs to provide a home for these data? Regardless of where the data live, good metadata are essential for data to be trusted and truly usable.

Interoperability

More open water data from state and local agencies presents exciting opportunities, as well as challenges, for combining water data across jurisdictional boundaries. Good metadata, data dictionaries, and data literacy will become increasingly important to ensure data are correctly used. Until data becomes more standardized, there is a need to provide crosswalks (Rosetta stones) between definitions and datasets. Such crosswalks can help to provide messaging and context to mitigate misuse, particularly when integrating data across jurisdictional boundaries. Addressing technical challenges provides great opportunities to regularly convene stakeholders and build communities with enough trust to have productive conversations moving towards standardization (Recommendation 2.2, Appendix I).

Financing Data Infrastructure

The ability for public agencies to participate in open water data efforts hinges on their ability to acquire adequate staff, technology, and financial resources. Public agencies must demonstrate that better data systems are cost efficient, create better outcomes, and reduce their requirements on regulated communities. For instance, California created time-savings by automating the process for water utilities to upload Safe Drinking

Water Act data to the state database. Another example is D.C. Water's efforts to create a digital twin of the Anacostia watershed in order to holistically and cost-effectively address water quality and compliance issues. The increasing costs of regulatory compliance may incentivize investing in the collection and sharing of water data to meet regulations more cost effectively. Regardless of the driver, quantifying and demonstrating benefits is essential to make the business case for public agencies to invest in data infrastructure. This is particularly challenging for water given the value of water data is transient, becoming increasingly valuable during drought or flood events and decreasing in value during normal conditions. The IoW must highlight and advocate these value propositions to assist public agencies to acquire the necessary resources.

In discussions of how to fund water data activities, the roundtables identified four primary funding sources for public agencies: (a) federal grants, (b) state agencies, (c) public demand, and (d) information services.

Federal Grants

Several federal government agencies, such as the USGS and EPA, provide human, technical, and financial resources to assist state and local governments with data collection, management, and analysis. The National Science Foundation also provides resources through their DataOne project to provide education and resources around data management practices, tools, documentation, standards, and so on. Federal grants are often used to initiate a data effort but don't support long-term operation and maintenance of data systems, with a few exceptions (e.g., USGS stream gauge data systems).

State Agencies

California passed AB 1755 without providing a stable source of funding for agencies to meet this mandate. Implementation of AB 1755 is estimated to cost $2 to 3 million annually, and while considerably less than the cost of new infrastructure (such as reservoirs or treatment plants), there are not obvious funding streams to dedicate towards data infrastructure. New Mexico's water data act dedicated $110,000, enough money for one full-time employee. The challenge of generating sustainable revenue streams for water data are not unique to California or New Mexico. State agencies have a role in ensuring long-term funding for mission critical systems; however, data infrastructure is a relatively new phenomenon that doesn't have a clear budget line. Even the well-regarded Water Data for Texas platform developed by TWDB is contingent on continued legislative approval, with much of their data efforts only occurring during "slow periods" because water data availability is not explicitly linked to meeting their mandated missions. States often have the will, but not the resources, to provide the best available data to ensure their water security and inform real-time decision-making. Yet the government is faced with a plethora of emergency issues and each dollar spent investing in data removes a dollar from directly addressing a current need. Those funds will likely never be allocated until compelling value propositions and business cases can be articulated.

Public Demand

The funding for public agencies comes from legislature, and legislature is motivated to fund needs expressed by their citizens. Enabling the government to invest in upgrading their data infrastructure requires outside demand for data transparency, availability, and accessibility. At a minimum, data users could write to their legislature to ask that they provide funds to support public agency's provision and distribution of data. This articulated demand would make it possible for state resources to be dedicated to data. For instance, TWDB's Water Data for Texas platform included visualizations and became their most popular website. Indeed, they received so much positive public response and demand that they have been able to continue allocating resources to this platform.

Information Services

Public agencies fund data collection through taxpayer dollars and believe the data belong to the public. However, open data are rarely used by the public unless the data are converted into information that addresses a felt need. Public agencies and data hubs may consider monetizing data services, tools, and applications using a subscription model. The development of information services should take a user-centered approach to provide maximum value to stakeholders. Public agencies and data hubs may also take a marketing approach to identify private sector users that would benefit from water data platforms and may help fund the provision of readily ingestible, standardized data into their systems as a more cost effective means than having their data analysts wrangle different datasets for each project. A user-centered approach to data will help create incentives for users to financially contribute to update and maintain data infrastructure (Principle 1.1, Appendix I). This approach requires government agencies to wrestle with their responsibility for vetting derived and model products and guiding decision-makers on their use.

Private Data

There is a culture growing around sharing public data. However, as the agricultural communities roundtable noted, the data gaps for creating robust water budgets often require private data or must be collected on private land. Participants identified four incentives for private entities to share data. These incentives were framed in the context of the agricultural community but likely apply to private utilities and other industrial water users.

Financial benefits. The agricultural community is already heavily regulated and there is a risk that providing more data will only increase regulations and create additional costs. Growers may accept the risk of sharing data if the monetary benefits now outweigh the risk of increased regulation in the future. Financial incentives may come from individual organizations paying for the data and ensuring only aggregated, anonymized versions of the data will be made public. Another financial benefit may be to award certificates to growers that demonstrate improved water quality or efficiency that can be translated to retailers paying premium prices for crops that can market a water friendly product (i.e., similar to organic crops, these could be certified as water-sustainable crops).

Incentive programs. An NGO could create an incentives program and serve as a neutral data hub that would not be required to provide data through a FOIA or a lawsuit, ensuring the protection of private data. Incentive programs could be particularly compelling for data needed to address downstream water quality problems. For instance, the development of markets where downstream utilities could pay growers to take unproductive land off the market and produce huge water quality benefits could lead to positive outcomes. The potential solutions to a large-scale water management problem will require data to be collected and shared whether by regulation, water quality markets, or supply chain peer-pressure.

Controlling the message. Growers and utilities may share data as part of an educational campaign and address societal misconceptions around agricultural water use. Utilities similarly believe the public does not appreciate how successful they are at providing safe, reliable drinking water. A universal problem in any industry is that while 90% of the industry is in regulatory compliance, the few out of compliance are the stories highlighted by the media. Sharing data can empirically support and frame the narratives and educational efforts of growers and utilities.

Fear of regulation. "*What is coming is more regulation and regulation of data*." While private industry fears being penalized for sharing data, there is currently an opportunity to establish the terms by which they surrender their data prior to regulation (which often follow a crisis). Industry can negotiate safe harbors in exchange for data. For example, USDA and EPA jointly launched the Minnesota Agricultural Water Quality Certification Program in 2013 as a voluntary opportunity for growers to implement and maintain approved management practices. In return, participating growers are exempt from any new water quality regulations implemented over the next 10 years.

How will private industries share their data? It is likely that industries will only be willing to share data through entities they consider to be neutral and capable of ensuring data privacy and security. The agricultural community identified agricultural cooperatives, soil and conservation districts, and private NGOs (such as AgGateway) as potential trusted hubs. Utilities and other industries will need to identify or create other trusted communities to provide data services.

APPENDIX I: FINDINGS AND RECOMMENDATIONS FROM THE INTERNET OF WATER REPORT

FINDINGS AND PRINCIPLES

FINDING 1: THE VALUE OF OPEN, SHARED, AND INTEGRATED WATER DATA HAS NOT BEEN WIDELY QUANTIFIED, DOCUMENTED, OR COMMUNICATED

Principle 1.1: A user-based approach will maximize the value of water data.

FINDING 2: MAKING EXISTING PUBLIC WATER DATA OPEN IS A PRIORITY

Principle 2.1: All public water data needed to characterize and forecast water budgets should be open by default, discoverable, and digitally accessible.

Principle 2.2: Water data standards to promote interoperability, efficiency, and user-flexibility will evolve in response to user demand.

Principle 2.3: Data producers are responsible for sharing data of known quality and documenting essential metadata; end users bear final responsibility for determining whether the data is fit for use.

Principle 2.4: Data should be shared as openly as possible, consistent with the principle that any security and privacy risks associated with sharing need to be balanced with the potential benefits.

FINDING 3: THE APPROPRIATE ARCHITECTURE FOR AN "INTERNET OF WATER" IS A FEDERATION OF DATA PRODUCERS, HUBS, AND USERS

Principle 3.1: Control and responsibility over data is best maintained by data producers.

Principle 3.2: A federated system of public water data hubs provides scalability and financial stability to better meet the diverse needs of data users.

Principle 3.3: A backbone organization should link data hubs and facilitate governance of the system, but not govern the production or use of data.

RECOMMENDATIONS

ACTION 1: ARTICULATE A VISION

Recommendation 1.1: Articulate a vision of sustainable water resource management and stewardship enabled by open, shared, and integrated public water data.

Recommendation 1.2: Initiate an Internet of Water through regional pilots that solve near-term water management problems for key stakeholders through shared and integrated water data.

ACTION 2: ENABLE OPEN WATER DATA

Recommendation 2.1: Develop water data catalogs that identify all existing public water data maintained by states.

Recommendation 2.2: Develop tools for opening existing, public water data and enable the use of those tools by producers and users.

Recommendation 2.3: Bind regulation, management practices, permitting, and funding to the provision of open data.

ACTION 3: CREATE AN INTERNET OF WATER

Recommendation 3.1: Existing water data hubs should be stabilized and further resourced.

Recommendation 3.2: A backbone organization should be formed to structure and enable a system of federated data.

Recommendation 3.3: The backbone organization should be a non-profit organization but with a cooperative agreement with a federal, non-regulatory agency.

Recommendation 3.4: Develop proof-of-concept on integrating data from multiple hubs to advance a water budget.

APPENDIX II: ACRONYMS

AB 1755	California's Open and Transparent Water Data Act (Assembly Bill 1755)
DWR	Department of Water Resources
EPA	Environmental Protection Agency
ET	Evapotranspiration
FOIA	Freedom of Information Act
GCD	Groundwater Conservation District
GLERL	Great Lakes Environmental Research Laboratory
GLOS	Great Lakes Observing System
GIS	Geographic Information System
IoW	Internet of Water
NASA	National Aeronautics and Space Administration
NGO	Non-governmental Organization
NOAA	National Oceanic and Atmospheric Administration
OpenET	Project to provide open evapotranspiration data
SGMA	Sustainable Groundwater Management Act
TWDB	Texas Water Development Board
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WaDE	Western States Water Council's Water Data Exchange program